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3.	Full name, address and postcode of the or of each applicant (*underline all surnames*)	KONINKLIJKE PHILIPS ELECTRONICS N.V. GROENEWOUDSEWEG 1 5621 BA EINDHOVEN THE NETHERLANDS
	Patents ADP Number (*if you know it*)	07419294001
	If the applicant is a corporate body, give the country/state of its incorporation	THE NETHERLANDS
4.	Title of the invention	METHOD OF PRODUCING AN ELECTRONIC DEVICE, ELECTRONIC DEVICE AND APPARATUS FOR IMPLEMENTING THE METHOD
5.	Name of your agent (*if you have one*)	
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DESCRIPTION

METHOD OF PRODUCING AN ELECTRONIC DEVICE, ELECTRONIC DEVICE AND APPARATUS FOR IMPLEMENTING THE METHOD

The present invention relates to a method of producing an electronic device comprising a plurality of electro-optical elements on a surface of a carrier, the carrier surface including an electrode structure.

The present invention also relates to an electronic device comprising a carrier having a carrier surface including an electrode structure and a plurality of electro-optical elements mounted on the carrier surface.

Several electronic devices utilize electro-optical elements to implement a targeted function of the device. Such electro-optical elements can be based on the principle that the application of an electrical field or a current will alter the orientation or configuration of the electro-optical material, which has an impact on the interaction of the material with light. For instance, the electrical field induces a change in orientation or configuration of the electro optical material that may allow light to pass the electro-optical element, and electro-optical elements being based on such a principle are therefore also referred to as light-valve elements.

The class of electronic devices including electro-optical elements include electrophoretic displays like e-ink devices and liquid crystal displays (LCDs), with the latter having become increasingly popular over recent years. LCDs can be found in a wide range of products, from handheld electronic devices like personal digital assistants and mobile phones to computer monitors and television sets.

Currently, much effort is being put in upscaling the dimensions of these electronic devices, e.g. LCDs. However, traditional production methods of LCDs, in which a liquid crystal material is deposited between two glass or polymer plates, are not ideal for such efforts, because increasing the size of

the substrate panes makes them difficult to handle. In addition, large substrate panes require large and heavy machinery, which makes the production process costly.

European patent application EP 1065553 A1 discloses an alternative method for producing a liquid crystal display. A layer of a mixture of a polymer precursor and a liquid crystal (LC) material is deposited on a transparent substrate carrying an orientation layer, after which the mixture is exposed to UV light in a photolithographic step. In this step, the polymer precursor is polymerized to form sidewalls between the desired pixels of the LCD. Subsequently, the rest of the mixture is exposed to UV light. This triggers a phase separation in which the polymer precursor is polymerized to form a continuous top layer on top of the polymer sidewalls, and in which the LC material is trapped between the polymer top layer, the polymer sidewalls and the substrate, thus forming a plurality of pixels on the substrate, with the polymer top layer serving as a second substrate.

However, it is a serious drawback of this method that several photolithography steps are still required to form the separate LC pixels, for instance because the development and production of masks is costly.

Inter alia, it is an object of the present invention to at least reduce the number of required photolithographic steps in the production of an electronic device according to the opening paragraph.

It is another object to provide an improved electronic device according to the opening paragraph.

It is yet another object of the present invention to provide an apparatus for implementing the method of the present invention.

According to an aspect of the present invention, there is provided a method of producing an electronic device comprising a plurality of electro-optical elements on a surface of a carrier, the method comprising the steps of depositing a plurality of discrete droplets of a first liquid on the carrier surface, the first liquid comprising a mixture of a first electro-optical material and a first

polymer precursor; and forming the plurality of electro-optical elements by exposing the plurality of discrete droplets to a stimulus for polymerizing the polymer precursor of a discrete droplet of the first liquid into a discrete polymer layer enclosing the first electro-optical material of the discrete droplet between said polymer layer and the carrier surface.

By depositing discrete droplets of a mixture of an electro-optical material such as a liquid crystal material and a polymer precursor over the electrode structure on the carrier surface, the discrete electro-optical elements, e.g., pixels, are predefined by the droplets. Such an electro-optical element may be formed by a single droplet or, if desired, formed by merging a plurality of droplets together by depositing them on the same location, i.e., on top of each other, on the carrier surface. This has the advantage that no photolithography step is required to acquire separate electro-optical elements. The droplets can simply be deposited by means of known printing techniques such as piezo-electric or continuous inkjet printing or bubble jet printing. Depending on the polymer precursor, the polymerization reaction can be initiated over the whole carrier surface by applying an appropriate stimulus like UV light exposure, heat, electron beam exposure and other known suitable polymerization initiators. Consequently, the production method of the present invention is cheaper and more versatile than the prior art production methods.

An additional advantage is that the electronic device size to be produced on a single carrier can be increased without causing an excessive increase in production cost, due to the fact that photolithographic masks are not necessarily required in the production process of the electronic device of the present invention. Also, there is no technical limitation to the number of electronic devices that may be produced on a single carrier, which improves efficiency of the production process, thus further reducing production cost.

The carrier surface may be modified by depositing an electrode structure such as an interdigitated electrode structure for controlling the liquid crystal elements with in-plane switching effects. In case of the electro-optical material being an LC material, the carrier surface may be modified by depositing an orientation layer such as a rubbed polyimide alignment layer or a

photo-aligning material like a cinnamate or a coumarin containing polymer prior to the deposition of the droplets, in order to ensure that the LC material adopts the required orientation in the electro-optical element. In addition, the carrier surface may be extended with other optical layers such as polarization filters, retardation layers, color filters and so on. The LC material may be chosen to, for instance, implement electrically controlled birefringence (ECB), twisted nematic (TN), super twisted nematic (STN), optically compensated birefringence (OCB), vertically aligned nematic (VAN), ferroelectric (FE) or in-plane switching (IPS) LC effects in combination with appropriate electrode structures and alignment layers.

An additional advantage of the production method of the present invention is that the shape of the arrangement of the plurality of electro-optical elements is no longer governed by the shape of the carrier surface. By depositing the electro-optical material at the pixel level, the electro-optical elements can be deposited on a predefined part of the carrier surface, thus forming predefined shapes like images. This is particularly advantageous for electronic devices being arranged to display fixed images.

In an embodiment, the step of depositing the plurality of discrete droplets is preceded by the step of depositing a pattern of wall structures on the carrier surface for creating a plurality of bordered domains on the carrier surface, a droplet from the plurality of discrete droplets being deposited in such a bordered domain. The deposition of a plurality of wall structures has the advantage that the wall structures prevent the individual droplets from further spreading, which prevents droplets from becoming too thin or from merging with a neighbouring droplet. Consequently, electro-optical elements having a near flat surface can be obtained.

Alternatively, the step of depositing a plurality of discrete droplets is preceded by the step of depositing a plurality of regions of a nonwetting material on the carrier surface. The contact angle of the droplets with this nonwetting layer is substantially larger than the contact angle of the droplets with the carrier substrate. Consequently, the nonwetting regions prevent the excessive spreading of droplets and neighbouring droplets from merging.

In another embodiment, the method further comprises the steps of depositing a plurality of discrete droplets of a second liquid on the carrier surface, the second liquid comprising a mixture of a second electro-optical material and a second polymer precursor; and forming a further plurality of electro-optical elements by exposing the plurality of discrete droplets of the second liquid to a second stimulus for polymerizing the second polymer precursor into a further discrete polymer layer enclosing the second electro-optical material between said further polymer layer and the carrier surface. These steps are preferably executed substantially in parallel to improve production efficiency. Even though the first electro-optical material and the second electro-optical material may be the same material, the fact that the method of the present invention deposits each electro-optical element individually can be used to deposit different types of electro-optical material at a single carrier surface. For instance, a first liquid crystal material and a second liquid crystal material can be chosen to define different electro-optical elements, e.g., different colour pixels. This way, the intended performance of the electro-optical elements can be improved by depositing the appropriate electro-optical materials. It will be obvious to those skilled in the art that this approach can be extended to any number of different liquids, e.g., three different liquids for a RGB colour display device, and so on.

After the formation of the electro-optical elements, the electronic device may be further processed. For instance, the method of the present invention may further comprise the step of depositing a further electrode structure on a polymer layer of the plurality of electro-optical elements to produce an electronic device having electro-optical elements sandwiched between a bottom electrode structure and a top electrode structure or to produce an electronic device having a single electrode structure opposite the carrier surface.

In addition, the method may further comprise the steps of covering the plurality of electro-optical elements with a light reflecting coating in the case of reflective TN, STN, ECB and IPS LC material to provide for a light-reflective electronic device and/or covering the plurality of electro-optical elements with a

planarization layer to facilitate further processing steps on the electronic device. Also, a step of adding a light-polarizing layer to the carrier may be executed prior to or after depositing the electro-optical elements. This is particularly useful in the case of the electronic device being a reflective or transmissive display having a transparent carrier.

According to a second aspect of the invention, there is provided an electronic device comprising a carrier having a surface and a plurality of electro-optical elements positioned on the carrier surface, each of the electro-optical elements having a discrete first polymer layer enclosing a first electro-optical material between said layer and the carrier surface.

Such an electronic device can be formed by executing the steps of the method of the present invention. It is emphasized that the aforementioned various advantageous embodiments of said method could be used to produce analogous advantageous embodiments of the electronic device of the present invention.

An additional advantage is obtained if the electronic device comprises a flexible carrier. A well-known problem with having a substantially continuous layer of electro-optical elements on a surface of a flexible carrier, e.g., a layer of LC pixels as disclosed in EP 1065553 A1, is that upon bending the surface, the stress on the inner and outer surfaces of the electronic can cause damage to those surfaces, thus damaging the LC pixels of the electronic device. The electronic device of the present invention suffers less, if at all, from this problem, especially when the plurality of discrete electro-optical e lements is not covered by an additional layer. Because the electro-optical elements are separated from each other, the outer surface does not experience tensile loading forces when the substrate is bent, thus providing an improved flexible electronic device.

According to a further aspect of the invention, there is provided an apparatus for producing an electronic device comprising a plurality of electro-optical elements on a surface of a carrier, the apparatus comprising receiving means for receiving the carrier and depositing means for depositing a plurality of discrete droplets of a liquid on the carrier surface, the liquid comprising a

mixture of an electro-optical material and a polymer precursor, the depositing means being arranged opposite the receiving means, with at least one of the receiving means and the depositing means comprising mechanical translation means for changing an orientation of the depositing means over a first part of the carrier surface to an orientation over a second part of the carrier surface. Such an apparatus is capable of depositing the droplets of a first liquid on the carrier surface in accordance with the method of the present invention.

In an embodiment, the apparatus further comprises means for forming the plurality of electro-optical elements by exposing the plurality of discrete droplets to a stimulus for polymerizing the polymer precursor of a discrete droplet of the liquid into a discrete polymer layer enclosing the electro-optical material of the discrete droplet between said polymer layer and the carrier surface. The additional means ensure that the apparatus is also capable of implementing the step of forming the polymer layers in accordance with the method of the present invention.

Advantageously, the depositing means comprise a printing head having a plurality of nozzles. This increases the efficiency of the implementation of the method of the present invention, because a larger number of droplets can be deposited at the same time.

It is a further advantage if a first subset of the plurality of nozzles is coupled to a reservoir for containing a first liquid comprising a mixture of a first electro-optical material and a first polymer precursor and a second subset of the plurality of nozzles is coupled to a reservoir for containing a second liquid comprising a mixture of a second electro-optical material and a second polymer precursor. This way, droplets having different compositions can be deposited at the same time, which is particularly advantageous for the production of colour display devices via the method of the present invention.

The invention is described in more detail and by way of non-limiting examples with reference to the accompanying drawings, wherein:

Figs 1-3 schematically depict various embodiments of the method and electronic device of the present invention;

Fig. 4 schematically depicts another embodiment of the electronic device of the present invention;

Fig. 5 schematically depicts a prior art display device and a display device of the present invention having bent carriers; and

Fig. 6 schematically depicts an apparatus for implementing the method of the present invention.

It should be understood that the Figures are merely schematic and are not drawn to scale. It should also be understood that the same reference numerals are used throughout the Figures to indicate the same or similar parts.

Fig. 1a shows a carrier 10 including an optional electrode structure 12. It is emphasized that Fig. 1 and the following Figs. show an embedded electrode structure 12 for reasons of clarity only. It should be understood that the surface of the carrier 10 preferably may also be defined by placement of the electrode structure 12 on top of the carrier 10. The electrode structure 12 can be formed on top of the carrier 10 from known materials, e.g., Indium Tin Oxide (ITO), and by known techniques for forming electrode structures on a carrier 10. The carrier 10 may comprise any suitable material, e.g., glass, polymer, or even non-obvious materials as modified wood, ceramics or modified paper. Optionally, the surface of carrier 10 that carries the optional electrode structure 12 may also be further modified prior to the formation of the electro-optical elements on the surface. For instance, if the electro-optical elements are light valves utilizing light polarization effects, e.g., liquid crystal elements, a light-polarizing layer 14 may be deposited on the surface of carrier 10 prior to the formation of the electro-optical elements on the carrier surface. The light-polarizing layer 14 may be formed from known light-polarizing materials. Alternatively, a light-polarizing layer may be placed on a further surface of the carrier 10 substantially in parallel with the surface including the electrode structure 12. In addition, an optional orientation layer 16 may be

deposited on the surface of carrier 10. The orientation layer 16 may be formed from known materials such as polyimides, which may be a rubbed polyimide such as AI3046, which is supplied by the JSR electronics company of Japan to achieve a desired orientation direction of an electro-optical material like a liquid crystal material. Alternatively, photo-aligning materials such as cinnamates and coumarin may be used, which induce orientation in an electro-optical material like a liquid crystal material after being exposed to linearly polarized light.

In a next step, the precursors for a plurality of electro-optical elements are deposited on the surface of carrier 10. The result of this depositing step is shown in Fig. 1b, where a plurality of discrete droplets 100, 120 and 140 have been deposited on the carrier surface. The deposition can be achieved by means of known printing techniques such as piezo-electric inkjet printing, continuous printing and bubble jet printing. The droplets may have been deposited as single droplets or as a deposition of a plurality of droplets in one location in order to achieve a large droplet comprising a plurality of smaller droplets. The printer used for the deposition of the droplets 100, 120 and 140 may be a multi-nozzle printer, in which case the droplets 100, 120 and 140 may be printed at the same time in a parallel printing step, which makes the production process of the electronic device more efficient.

The droplets 100, 120 and 140 may all be of a first liquid, the first liquid comprising a mixture of a first electro-optical material 102, 122, 142 and a first polymer precursor 104, 124, 144, in which case the plurality of electro-optical elements to be formed from droplets 100, 120, 140 are all of the same type. A polymerization initiator may also be present in the liquid to start a polymerization reaction upon subjecting the droplets to an appropriate stimulus. As emphasized before, the droplets 100, 120 and 140 can be printed onto the carrier 10 using known printing techniques.

The individual deposition of the droplets has the large advantage that the liquids from which droplets 100, 120 and 140 are formed can be chosen to differ from each other in that at least the electro-optical materials 102, 122 and 142 are different in each liquid. Optionally, the polymer precursors 104, 124,

144 as well as the polymerization initiators may also be different. When the electro-optical materials 102, 122 and 142 are different in each liquid, several pluralities of different electro-optical elements may be formed, which for instance may be beneficial if the electro-optical elements are to define RGB pixels of a colour display device, in which case different electro-optical materials 102, 122 and 142 can be chosen to generate RGB pixels including an electro-optical material that is particularly suited for that pixel type. The printing of several pluralities of droplets can for instance be achieved by using the various nozzles of a multi-nozzle printer to print droplets having such differing compositions, e.g., a first nozzle being arranged to print a first liquid comprising a mixture of a first electro-optical material and a first polymer precursor and a second nozzle being arranged to print a second liquid comprising a mixture of a second electro-optical material and a second polymer precursor. Another option to further optimize the production process is to use a different multi-nozzle head for the deposition of each of the various liquids.

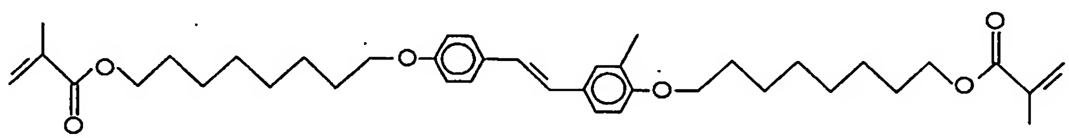
In a next step, the droplets 100, 120 and 140 are exposed to a stimulus for initiating a polymerization reaction of the polymer precursor 104, 124 and 144 to transform the droplets 100, 120 and 140 into electro-optical elements 110, 130 and 150. Such a stimulus may for instance be exposure to UV light or heat if the polymerization reaction to be induced in the respective droplets 100, 120 and 140 is of a photo-induced or thermally induced type, respectively. Obviously, a suitable polymerization initiator has to be chosen accordingly. Polymerization can also be directly induced by an electron beam.

Upon exposure of the droplets to the stimulus, the photo-initiated polymerization reaction takes place at the surface of the droplets 100, 120 and 140 and triggers a phase-separation within these droplets. Consequently, the respective electro-optical materials 102, 122 and 142 are enclosed between the surface of the carrier 10 and the respectively formed discrete polymer layers 114, 134 and 154.

A non-limiting example of a suitable composition of a first liquid to be deposited in droplet form as electro-optical element precursors on a carrier is as follows:

50 weight percent (wt %) of a liquid crystal mixture, for instance the mixture E7, which is marketed by Merck, the liquid crystal mixture being an embodiment of the electro-optical material 112;

44.5 wt % photo-polymerizable isobornylmethacrylate (supplied by Sartomer) and 4.5 wt% of a stilbene dimethacrylate dye



, the synthesis of which has been disclosed in PCT patent application WO 02/42382 and which is hereby incorporated by reference, the two acrylates being an embodiment of the polymer precursor 114

; and

0.5 wt% benzildimethylketal, which is marketed by Ciba-Geigy under the trade name Irgacure 651.

A non-limiting example of the printing process of the present invention using the embodiment of the first liquid given above is as follows. In a test setup, a 6x6 inch square glass carrier 10 was provided with an interdigitated electrode structure 12 and a rubbed polyimide orientation layer AI3046 from the JSR electronics Company of Japan. The dimensions were chosen to fit 9 small displays on the carrier 10. It is emphasized that much larger dimensions for the carrier 10 are equally feasible, however. The carrier 10 was mounted on a computer controlled X-Y table having a variable speed of 1-30 mm/s.

A MicroDrop inkjet printing device was placed in a fixed position over the X-Y table. The dispensing head of the MicroDrop inkjet printing device included a glass capillary shaped into a nozzle on one side, the capillary being surrounded by a tubular piezo-activator for generating a pressure wave through the capillary. The pressure wave triggers the release of a droplet of

the first liquid from the capillary. The shape of the pressure wave as well as the diameter of the capillary nozzle can be varied to control the size of the droplets to be released. Here, a pressure wave having a single block shape and a 70 micron nozzle have been used, leading to droplet diameters of 60-75 micron at the nozzle exit, each droplet having having a volume of around 70 picoliter. Each of the droplets 100, 120 and 140 were formed on the carrier 10 by depositing 75 droplets over a single part of the electrode structure 12.

The droplets 100, 120 and 140 were exposed to UV light from a Philips TL08 UV lamp with a light intensity of 0.1mW/cm^2 for 30 minutes at 40° C, after which the formation of the electro-optical elements 110, 130 and 150 was completed.

The inclusion of a compound having a chromophore strongly absorbing in the UV region of the electromagnetic spectrum, i.e., the stilbene dimethacrylate dye in the example above, causes a gradient in the UV intensity through the droplets 100, 120 and 140. This effect may be amplified by the UV absorptions of the other components of the liquids used to form these droplets, like the other components of the polymer precursors 104, 124 and 144 and the electro-optical materials 102, 122 and 142. Consequently, the polymerization reaction predominantly takes place at the surface of the droplets 100, 120 and 140 facing the UV source. When other stimuli for triggering the polymerization reaction are used, care has to be taken that the polymerization reaction predominantly takes place at the surface of the droplets 100, 120 and 140.

At this point, it is emphasized that the viscosity of the liquid has a marked influence on the printing process. For instance, the operational ink viscosity range of suitable piezo-electric inkjet printers ranges from approximately 1-20 mPa.s. It should be understood that other ranges may be appropriate for different types of printing devices. If the liquid has a higher viscosity, heating of the nozzles of the printer is preferred to lower the viscosity. Apart from heating, the viscosity of the liquids used in the printing process from which the droplets 100, 120 and 140 are formed may also be controlled in a number of alternative ways.

A first option is to add an inert solvent to the liquid to lower its viscosity, like anisole or xylene. However, care has to be taken that the solvent is not too volatile, because this may lead to the solvent evaporating from the liquid before it has left the nozzle of the printer. This can lead to blockage of the printer nozzle, since this nozzle may be no more than a few tens of microns wide. Also, the evaporation speed of the solvent should not be too low, since this will slow down the process of the solvent evaporating from the droplets 100, 120 and 140, which has a negative impact on the production speed of the electronic devices of the present invention. It has been found that solvents having a vapour pressure in the range from 0.04 kPa to 4kPa at 298 K are most suitable for such an application. Care also has to be taken that the fraction of solvent remaining in the droplets 100, 120 and 140 is low enough before initiating the polymerization of the polymer precursors, because the solvent otherwise may interfere with the phase separation or with the correct functioning of the electro-optical material.

Alternatively, the various components that make up the liquids can be chosen to modify the viscosity of the liquid. For instance, the liquid crystal mixture E7 may be replaced by a lower viscosity liquid crystal material like the single component cyanobiphenyl liquid crystal marketed by Merck under the name K15 to lower the viscosity of the liquid given in the aforementioned example.

Also, a low viscous and volatile reactive monomer may be used to tune the viscosity of the liquids used as printing inks. Prior to the polymerization of the polymer precursors 104, 124 and 144, most of the volatile reactive monomer will already have evaporated and the remaining fraction will be incorporated in the polymer layers 114, 134 and 154, thus causing no interference with the electro-optical properties of the electro-optical materials 102, 122 and 142.

It is pointed out that in the case of multi-component electro-optical materials, the polymerization process may alter the composition of the electro-optical materials 102, 122 and 142, because some of the various components of the electro-optical materials may be partially enclosed in the respective

polymer layers 114, 134 and 154. This can be an unwanted phenomenon if the electro-optical properties of the electro-optical elements 110, 130 and 150 are affected as a consequence.

This can be avoided by formation of a small number of electro-optical elements on a small test carrier, with subsequent evaluation of the composition of the electro-optical materials in those electro-optical elements by for instance high performance liquid chromatography (HPLC). If the concentration of a component of the electro-optical material is discovered to be lower than intended, the fraction of this component in the first liquid can be increased and the test formation of the electro-optical elements can be repeated until the electro-optical materials in the electro-optical elements have the desired composition.

Fig. 1c schematically depicts the formed electro-optical elements 110, 130 and 150, which have been formed from respective droplets 100, 120 and 140. The electro-optical elements 110, 130 and 150, which may operate as pixels of a display device, have respective polymer layers 114, 134 and 154, which respectively have been formed from polymer precursors 104, 124 and 144, and which respectively enclose the electro-optical materials 102, 122 and 142 between their inner surfaces and the surface of carrier 10. This way, a plurality of electro-optical elements is formed that each have a discrete polymer layer with a substantially uniform thickness from the first contact point with the surface of the carrier 10 to the second contact point with the surface of the carrier 10. The electronic device 1 shown in Fig. 1c may be the end product, in which case the electrode structure 12 may be an electrode structure suitable for controlling the electro-optical materials 102, 122 and 142 from a single side using in-plane switching. This can for instance be achieved using an interdigitated electrode structure.

At this stage, it is pointed out that the use of the wording 'discrete' to define a property of the droplets 100, 120 and 140 or a property of the polymer layers 114, 134 and 154, should not be interpreted to mean that the droplets 100, 120 and 140 or the polymer layers 114, 134 and 154 have to be completely separated from each other. Minor contact areas between the

droplets 100, 120 and 140 or the polymer layers 114, 134 and 154 may exist near the surface of the carrier 10 without departing from the scope of the present invention. It will be understood that the size of such contact areas between two neighbouring droplets will have to remain small enough to prevent neighbouring droplets from merging.

In Fig. 1d, an optional further processing step on the electronic device shown in Fig. 1c is depicted. In this step, a planarization layer 24 is deposited on top of the plurality of electro-optical elements 110, 130 and 150. The planarization layer 24, which may be formed from any known suitable planarization material, facilitates the deposition of further layers such as a polarizing layer (not shown) or the deposition of a further electrode structure 32 on the plurality of electro-optical elements 110, 130 and 150 opposite to the electrode structure 12, as shown in Fig. 1e. If, however, the electro-optical elements 110, 130 and 150 are flat enough, the planarization layer 24 may be omitted and the further electrode structure 32 may also be deposited directly on top of the polymer walls 114, 134 and 154 of the respective electro-optical elements 110, 130 and 150.

The further electrode structure 32 and the electrode structure 12 may form the rows and columns of the electronic device 1. Alternatively, the further electrode structure 32 may be an interdigitated electrode structure to facilitate in-plane switching of the electro-optical elements, in which case electrode structure 12 may be omitted. The further electrode structure 32 may be formed from the polymer semiconductor material polyethylenethioxythiophene (PEDOT) or similar materials that have the advantage that they can be processed at a temperature low enough to avoid damage to the electro-optical elements 110, 130 and 150.

Alternatively, the layer 24 may be formed of a light reflecting coating in the case of the electro-optical materials 112, 132 and 152 comprising reflective TN, STN, ECB and IPS LC materials, to form a reflective display device. It should be obvious to those skilled in the art that, where possible, the aforementioned processing steps may be combined or interchanged without departing from the teachings of the present invention.

At this point, it is emphasized that the droplets 100, 120 and 140 in Fig. 1b and the electro-optical elements 110, 130 and 150 in Fig. 1c have been represented having a hemi-spherical shape by way of non-limiting example only. A hemi-spherical shape may be preferable in application domains where the electro-optical elements need to have lens-like characteristics, in which case the width W of the formed electro-optical element is of a similar magnitude as height H. In contrast, in application domains where the electro-optical elements have to operate as light valves, e.g., LCDs and electrophoretic displays like E-ink displays, it may be preferable to have droplets with flattened surfaces in order to avoid unwanted optical effects, in which case width W can be much larger than height H. For example, W may be 1,000 micron or more, whereas H may typically be a few tenths of microns.

The shape adopted by the electro-optical elements 110, 130 and 150 can be controlled by modifying the contact angle α of the droplets 100, 120 and 140 with the surface of the carrier 10. A low contact angle α, i.e. a good wetting, facilitates the formation of a thin electro-optical element having a relatively flat surface, especially if the element is formed from a large droplet formed by depositing a plurality of smaller droplets in the same location at the surface of the carrier 10. In case of an LCD, electro-optical elements 110, 130 and 150, having a relatively flat surface can be especially advantageous when the electronic device 1 is a display device, because the light passing through such electro-optical elements at most experiences minor distortion, thus yielding a display device having a good image quality. When the contact angle α of the discrete droplets 100, 120 and 140 with the carrier 10 is low, care has to be taken that the discrete droplets 100, 120 and 140 do not merge with neighbouring discrete droplets. Also, height H of the droplets should be large enough to enable the proper functioning of the electro-optical materials 102, 122 and 142 in the corresponding electro-optical elements 110, 130 and 150. This is particularly relevant if the electro-optical materials 102, 122 and 142 are LC materials, in which case the height H of the electro-optical elements 110, 130 and 150 should be substantially constant throughout the full width W of

the electro-optical elements 110, 130 and 150 to ensure a proper LC effect in the electro-optical elements 110, 130 and 150. Furthermore, prevention of excessive spreading of the droplets 100, 120 and 140 will improve the resolution of the electronic device to be produced.

To enable the droplets 100, 120 and 140 to be printed on the surface of the carrier 10 assuming the desired form, the surface of carrier 10 may be modified prior to the deposition of the droplets 100, 120 and 140. In Fig. 2, an example of such a modification is shown. Fig. 2a shows the carrier 10 with an electrode structure 12, an optional polarization layer 14 and an optional orientation layer 16 on its surface, on which a photosensitive lacquer 200 is deposited. The photosensitive lacquer 200 is patterned in a photolithography step to form a pattern of wall structures 202 on the surface of the carrier 10, as shown in Fig. 2b. The pattern of wall structures 202 forms a relief pattern on the surface of the carrier 10. Alternatively, such a relief pattern can for instance also be obtained through photo-embossing, injection moulding, screenprinting, microcontact printing or two-step photo-polymerization techniques.

Next, the droplets 100, 120 and 140 are deposited in separate cavities between the wall structures 202 formed on the modified carrier 10, leading to an intermediate electronic device as shown in Fig. 2c. The deposition of the droplets 100, 120 and 140 into a bordered area has the advantage that spreading of the droplets is prevented and that the area can be filled up, thus providing droplets 100, 120 and 140 having a sufficient height H. At this point, it is emphasized that the shape of the wall structures 202 is not limited to the shape shown in this example. For instance, tapered walls or a multitude of stacked polymer layers forming the walls may also be used without departing from the scope of the present invention.

Furthermore, it will be understood that the modification steps of the surface of the carrier 10, e.g., the deposition of the optional orientation layer 16, may also take place after the development of the wall structures 202.

An alternative carrier modification method to achieve these advantages is shown in Fig. 3. In Fig. 3a, a stamp 300 such as a polydimethylsiloxane (PDMS) stamp is used to print regions 302 of a nonwetting material on the

surface of the carrier 10. If required, the regions 302 may be offset printed on top of an optional orientation layer 16, such as the aforementioned Al3046. As an ink for the PDMS stamp 300, a homeotropic alignment material such as SE7511 from the Nissan Chemical Company from Japan may be used, although the use of other known offset printing inks, e.g., polyimides, is also possible.

The printing of the regions 302, which may be done with a stamp simultaneously contacting the whole surface of the carrier 10 or with a stamp that is rolled over the surface of the carrier 10, provides a plurality of bordered domains on the carrier surface, as shown in Fig. 3b. The nonwetting regions 302 ensure that the wetting on the surface carrier 10 predominantly takes place in the bordered domains upon deposition of the droplets 100, 120 and 140, thus yielding an intermediate structure of the electronic device as shown in Fig. 3c. Good nonwetting properties of the carrier surface can be achieved by choosing a nonwetting material, e.g., the aforementioned SE7511, which causes the contact angle α of the droplets 100, 120 and 140 with the carrier 10 to be at least 10 degrees larger at the regions 302 compared to the contact angle α with the untreated regions of the carrier 10.

Rather than using offset printing, the regions 302 of a dewetting material may be also be deposited by alternative printing techniques such as microcontact printing, flexo-graphic printing, screen printing, inkjet printing, gravure printing, gravure-offset printing or tampon printing.

In Fig. 4, an advantageous embodiment of an electronic device 1 according to the present invention is depicted. A predefined part of the surface of carrier 10 of the electronic device 1 carries a plurality of electro-optical elements 110 arranged in a corresponding predefined pattern. It will be appreciated by those skilled in the art that with the production method of the present invention, such an electronic device 1 can be easily produced, because the whole surface of the carrier 10 can be equipped with a regular electrode structure (not shown), with the predefined pattern of the electronic device being built-up by means of a plurality of discrete electro-optical elements 110, or, several pluralities of electro-optical elements, e.g., electro-

optical elements 110, 130 and 150 as previously shown. Rather than having to shape an electrode structure in a predefined pattern and cover the whole surface of the carrier 10 with electro-optical elements, which is a time-consuming and costly process typically associated with segmented display devices, the method of the present invention allows for a more facile way of producing such an electronic device, because the electro-optical elements 110 can be produced individually on top of the regular electrode structure, thus yielding a more simple and cheaper electronic device 1 that can be produced faster.

The fact that the electro-optical elements 110 are individually formed on the surface of carrier 10 also facilitates the formation of electronic devices 1 and in particular display devices having a non-rectangular shape, because the formation of the electro-optical elements 110 is no longer related to the shape of carrier 10. In fact, the shape of the carrier 10 may be any shape that allows the formation of a functioning electrode structure on its surface.

The electronic device 1 of the present invention also has particular advantages when the carrier 10 is a flexible carrier. Fig. 5a schematically depicts an electronic device 500 in a bent state. The electronic device 500, which can be produced using prior art production methods, such as for instance disclosed in PCT patent application WO 99/21052, has a plurality of electro-optical elements 520, which are typically separated by polymer walls or lithographic spacers 525 and which are sandwiched between a flexible carrier 510, which may be formed from a thin polymer such as a modified polycarbonate foil marketed by the Tejin company, and a polymer layer 530, which is sealed to the flexible carrier 510. Due to the presence of the top layer 530, the carrier 510 experiences an inward directed stress force in the bent state as indicated by arrows 540, whereas the top layer 530 experiences an outward directed stress force indicated by arrows 550. This causes a stress load on the electronic device 500 that may lead to the failure of the device. Also, the electro-optical elements 510 can deform under such stress loads, which in particular in the case of the electro-optical material in these elements being an LC material causes deterioration of the display qualities such as

variations in the grey scales of the various electro-optical elements 510 of the electronic device 500.

In comparison, Fig. 5b shows an electronic device 1 according to the present invention. The electronic device 1 has a flexible carrier 10, which may be formed from the same polymer substrate as that of electronic device 500 or another suitable flexible material, the carrier 10 carrying a plurality of discrete electro-optical elements 110 on its surface. Because the electro-optical elements 110 of the electronic device 1 of the present invention are not formed by a continuous layer such as a polymer layer 530 but are formed by separate discrete polymer layers 114 instead, the electronic device 1 is not subjected to a stress load upon bending of the carrier 10. Consequently, the performance of the electronic device 1 in general and of the electro-optical elements 110 in particular is not compromised when the electronic device is bent.

A further advantage of applying the present invention to flexible substrates is that the electro-optical elements of the present invention typically only have a height H as shown in Fig. 1c of a few tenths of microns, thus having a positive effect on the reduction of the overall thickness of the flexible electronic device. This is of particular relevance to matrix array electronic devices based on organic semiconductor materials, because the electro-optical printing technique of the present invention can be performed at temperatures that are low enough to ensure that the organic semiconductor materials are kept intact. In addition, such an electronic device 1 can be kept thin enough to be rolled up, without causing excessive stress to the various layers of the electronic device in its rolled-up state.

Fig. 6 shows an embodiment of an apparatus 600 for producing an electronic device 1 comprising a plurality of electro-optical elements on a surface of a carrier 10 by implementing the method of the present invention. An XY-table 620 is arranged to receive the carrier 10, which in this case carries an electrode structure 12. In the example shown in Fig. 6, 9 electrode structures 12 corresponding with 9 electronic devices to be produced are depicted as a non-limiting example only. The XY table 620 can be translated over tracks 624 under control of computer system 622.

Opposite the surface of the XY table 620 that carries the substrate 10, the apparatus 600 preferably includes a plurality of printing devices 640 in a fixed construction 644, although a single printing device 640 is also feasible. The printing devices 640 are arranged to deposit a plurality of discrete droplets of a liquid on the carrier surface. To this end, each of the printing devices 640 preferably includes a printing head 641 having a plurality of nozzles 642 with their outlets pointed towards the XY table 620, although single-nozzle printing heads 641 are also feasible. All of the nozzles 642 may be attached to a single reservoir (not shown) for containing a first liquid comprising a mixture of a first electro-optical material 102 and a first polymer precursor 104, in which case all the electro-optical elements to be formed will contain the same electro-optical material.

Alternatively, a subset of the nozzles 142 may be attached to a reservoir (not shown) for containing a first liquid comprising a mixture of a first electro-optical material 102 and a first polymer precursor 104, while another subset of the nozzles 142 may be attached to a reservoir for containing a second liquid comprising a mixture of a second electro-optical material 122 and a second polymer precursor 124, in which case different types of electro-optical elements can be deposited in parallel. Also, the printing devices 640 may comprise a plurality of printing heads 641 to further optimize the printing process of the present invention. The printing devices 640 may be known printing devices such as piezo-electric or continuous inkjet printing devices or bubble jet printing devices.

Preferably, the apparatus 600 also comprises means for forming the plurality of electro-optical elements such as an UV-lamp (not shown) or a heat source (not shown).

It will be understood by the skilled person that instead of having a translation table 620, fixed means 620, e.g., a fixed table, for receiving the carrier 10 and a plurality of printing devices 640 in a XY translation construction 644 can also be used without departing from the scope of the present invention.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word "comprising" does not exclude the presence of elements or steps other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The invention can be implemented by means of hardware comprising several distinct elements. In the device claim enumerating several means, several of these means can be embodied by one and the same item of hardware. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

CLAIMS

1. A method of producing an electronic device (1) comprising a plurality of electro-optical elements on a surface of a carrier (10), the method comprising the steps of:

- depositing a plurality of discrete droplets of a first liquid on the carrier surface, the first liquid comprising a mixture of a first electro-optical material (102) and a first polymer precursor (104); and
- forming the plurality of electro-optical elements by exposing the plurality of discrete droplets to a stimulus for polymerizing the polymer precursor (104) of a discrete droplet (100) of the first liquid into a discrete polymer layer (114) enclosing the first electro-optical material (102) of the discrete droplet (100) between said polymer layer (114) and the carrier surface.

2. A method as claimed in claim 1, wherein a discrete droplet (100) of the first liquid is formed by depositing a plurality of smaller droplets of the first liquid over a same respective part of the electrode structure (12).

3. A method as claimed in claim 1 or 2, wherein the step of depositing a plurality of discrete droplets is preceded by modifying the carrier surface by depositing an electrode structure (12) on the carrier surface.

4. A method as claimed in claim 1, 2 or 3, wherein the step of depositing a plurality of discrete droplets is preceded by modifying the carrier surface by depositing an orientation layer (16) on the carrier surface.

5. A method as claimed in any of the claims 1-4, wherein the step of depositing the plurality of discrete droplets is preceded by the step of depositing a pattern of wall structures (202) on the carrier surface for creating

a plurality of bordered domains on the carrier surface, a droplet (100) from the plurality of discrete droplets being deposited in such a bordered domain.

6. A method as claimed in any of the claims 1-4, wherein the step of depositing a plurality of discrete droplets is preceded by the step of depositing a plurality of regions (302) of a nonwetting material on the carrier surface.

7. A method as claimed in any of the preceding claims, wherein the first electro-optical material (102) comprises a liquid crystal material.

8. A method as claimed in any of the preceding claims, further comprising the steps of:

- depositing a plurality of discrete droplets of a second liquid on the carrier surface, the second liquid comprising a mixture of a second electro-optical material (122) and a second polymer precursor (124); and
- forming a further plurality of electro-optical elements by exposing the plurality of discrete droplets of the second liquid to a second stimulus for polymerizing the second polymer precursor (124) into a further discrete polymer layer (134) enclosing the second electro-optical material (122) between said further polymer layer (134) and the carrier surface.

9. A method as claimed in claim 8, wherein the step of depositing a plurality of discrete droplets of a first liquid on the carrier surface and the step of depositing a plurality of discrete droplets of a second liquid on the carrier surface are executed substantially in parallel.

10. A method as claimed in any of the preceding claims, wherein the second electro-optical material (122) comprises a further liquid crystal material.

11. A method as claimed in any of the preceding claims, further comprising the step of depositing a further electrode structure (3) on a polymer layer (114, 134, 154) of the plurality of electro-optical elements.

12. A method as claimed in of the preceding claims, further comprising the step of covering the plurality of electro-optical elements with a light reflecting coating.

13. A method as claimed in any of the preceding claims, the method further comprising the step of adding a light-polarizing layer (14) to the carrier (10), the light-polarizing layer (14) being arranged substantially parallel to the carrier surface.

14. A method as claimed in any of the preceding claims, further comprising the step of covering the plurality of electro-optical elements with a planarization layer (24).

15. An electronic device (1) comprising:

a carrier (10) having a surface; and

a plurality of electro-optical elements positioned on the carrier surface, each of the electro-optical elements (110) comprising a discrete polymer layer (114) enclosing a first electro-optical material (102) between said polymer layer (114) and the carrier surface.

16. An electronic device (1) as claimed in claim 15, wherein the carrier surface comprises an electrode structure (12).

17. An electronic device (1) as claimed in claim 15 or 16, wherein the carrier surface comprises an orientation layer (16).

18. An electronic device (1) as claimed in claim 15, 16 or 17, wherein the electronic device further comprises a pattern of wall structures (202) for

creating a plurality of bordered domains on the carrier surface; an electro-optical element (110) from at least a part of the plurality of electro-optical elements occupying such a bordered domain.

19. An electronic device (1) as claimed in claim 15, 16 or 17, wherein the plurality of electro-optical elements are separated from each other by means of nonwetting regions (302) on the carrier surface.

20. An electronic device (1) as claimed in any of the claims 15-19, wherein the first electro-optical material (102) comprises a liquid crystal material.

21. An electronic device (1) as claimed in any of the claims 15-20, the electronic device further comprising a plurality of further electro-optical elements positioned over further respective parts of the electrode structure (12), each of the further electro-optical elements (130) comprising a further discrete polymer layer (134) enclosing a second electro-optical material (122) between said second layer (134) and the carrier surface.

22. An electronic device (1) as claimed in any of the claims 15-21, wherein the second electro-optical material (122) comprises a further liquid crystal material.

23. An electronic device (1) as claimed in any of the claims 15-22, wherein the plurality of electro-optical elements carry a further electrode structure (32).

24. An electronic device (1) as claimed in any of the claims 15-23, wherein the plurality of electro-optical elements are covered by a light reflecting coating.

25. An electronic device (1) as claimed in any of the claims 15-24, wherein the carrier comprises a light-polarizing layer.

26. An electronic device (1) as claimed in any of the claims 15-25, wherein the plurality of electro-optical elements is covered by a planarization layer (24).

27. An electronic device (1) as claimed in any of the claims 15-26, wherein the carrier (10) is flexible.

28. An electronic device (1) as claimed in any of the claims 15-27, wherein the plurality of electro-optical elements are covering a predefined part of the carrier surface.

29. An electronic device (1) as claimed in any of the claims 15-28, wherein the electronic device is a display device.

30. An apparatus (600) for producing an electronic device (1) comprising a plurality of electro-optical elements on a surface of a carrier (10), the apparatus (600) comprising:

receiving means (620) for receiving the carrier (10); and

depositing means (640; 641; 642) for depositing a plurality of discrete droplets of a liquid on the carrier surface (12), the liquid comprising a mixture of an electro-optical material (102) and a polymer precursor (104), the depositing means (640; 641; 642) being arranged opposite the receiving means (620) with at least one of the receiving means (620) and the depositing means (640; 641; 642) comprising mechanical translation means for changing an orientation of the depositing means (640; 641; 642) from over a first part of the carrier surface to an orientation over a second part of the carrier surface.

31. An apparatus (600) as claimed in claim 30, the apparatus (600) further comprising means for forming the plurality of electro-optical elements by exposing the plurality of discrete droplets to a stimulus for polymerizing the polymer precursor (104) of a discrete droplet (100) of the liquid into a discrete polymer layer (114) enclosing the electro-optical material (102) of the discrete droplet (100) between said polymer layer (114) and the carrier surface.

32. An apparatus (600) as claimed in claim 30 or 31, wherein the depositing means (640; 641; 642) comprise a printing head (641) having a plurality of nozzles (642).

33. An apparatus (600) as claimed in claim 32, wherein a first subset of the plurality of nozzles (642) is coupled to a reservoir for containing a first liquid comprising a mixture of a first electro-optical material (102) and a first polymer precursor (104) and a second subset of the plurality of nozzles (642) is coupled to a reservoir for containing a second liquid comprising a mixture of a second electro-optical material (122) and a second polymer precursor (124).

ABSTRACT

METHOD OF PRODUCING AN ELECTRONIC DEVICE, ELECTRONIC DEVICE AND APPARATUS FOR IMPLEMENTING THE METHOD

The electronic device (1) of the present invention has a carrier (10) with a plurality of discrete electro-optical elements (110, 130, 150) mounted on the surface of the carrier (10). The electro-optical elements (110, 130, 150), which cover respective parts of the electrode structure (12) on the surface of the carrier (10), each have a polymer layer (114, 134, 154), which encloses an electro-optical material (102, 122, 142) between the polymer layer (114, 134, 154) and the surface of the carrier (10). The discrete electro-optical elements (110, 130, 150) have been formed by the individual deposition of discrete droplets of a liquid comprising the electro-optical material and a polymer precursor followed by exposure of the droplets to a stimulus triggering the polymerization of the polymer precursor.

<Fig. 1c>

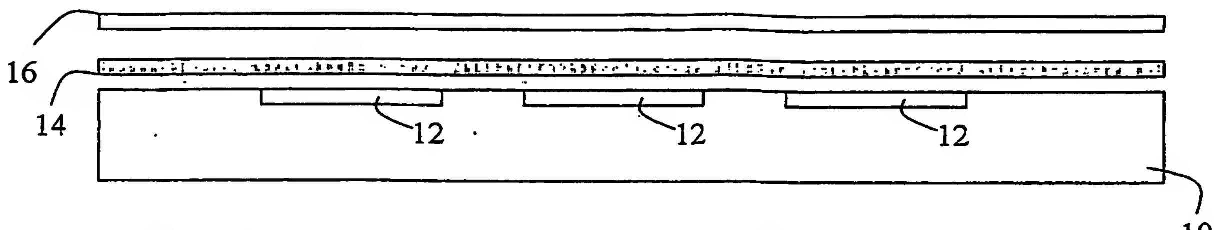


Fig. 1a

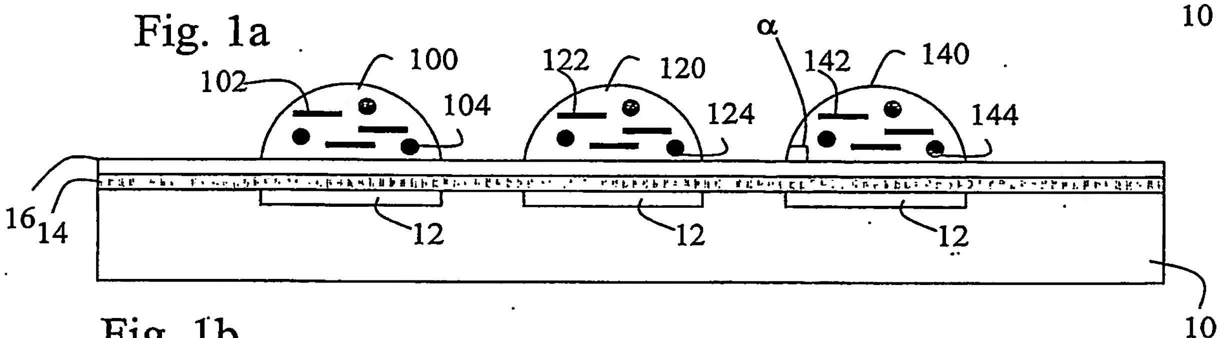


Fig. 1b

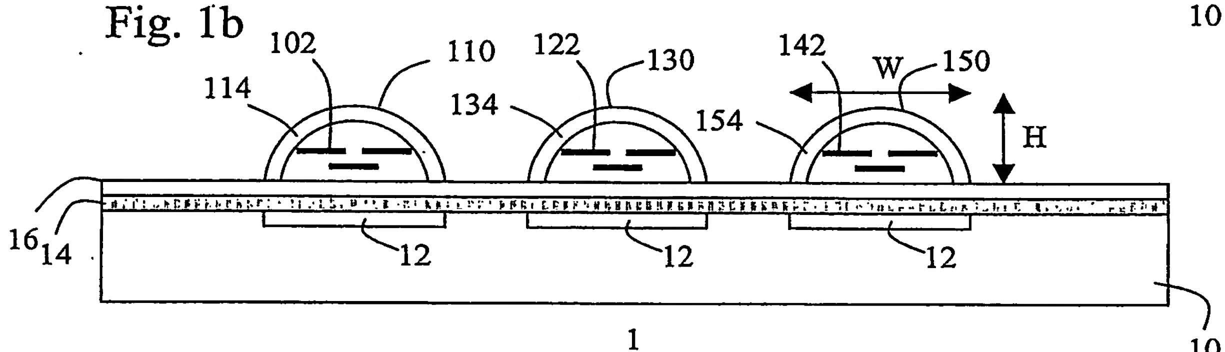


Fig. 1c

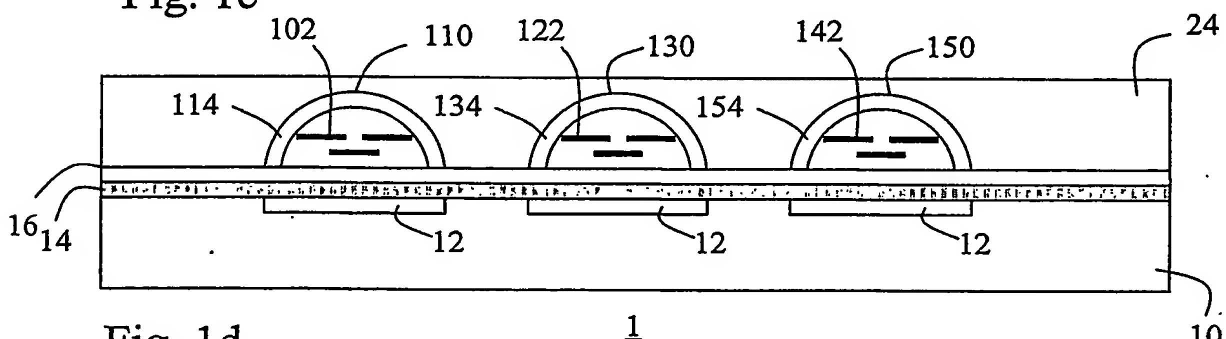


Fig. 1d

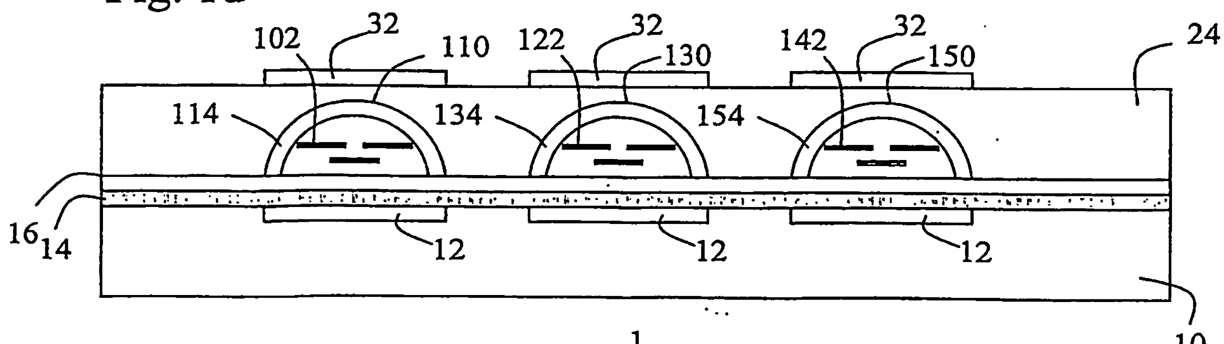


Fig. 1e

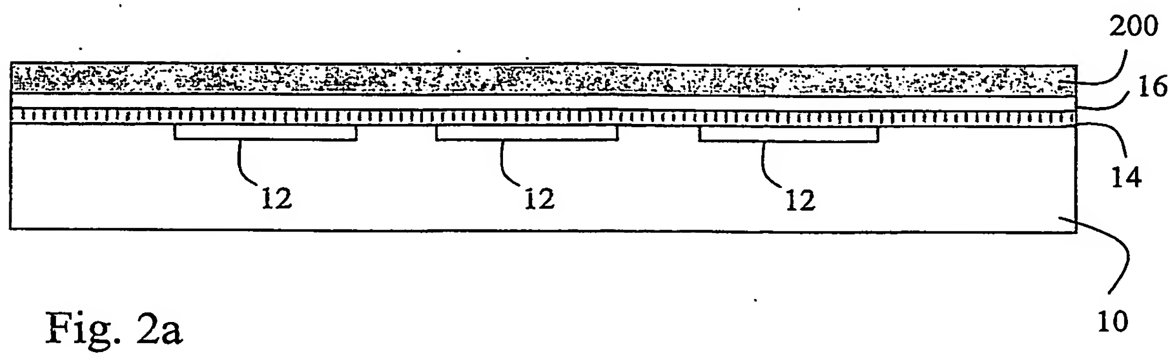


Fig. 2a

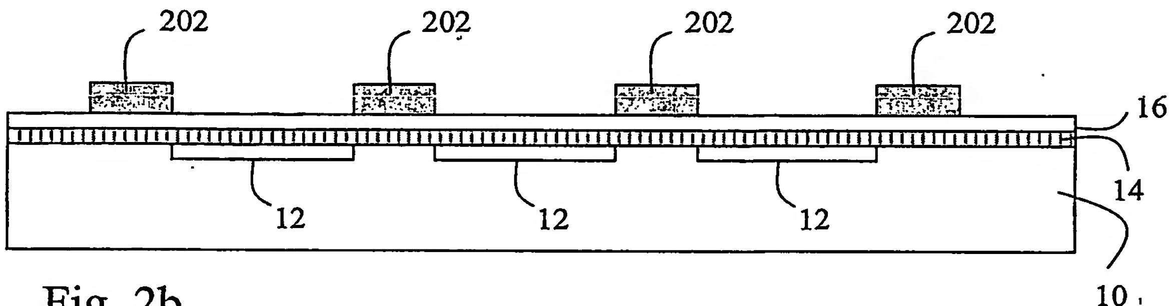


Fig. 2b

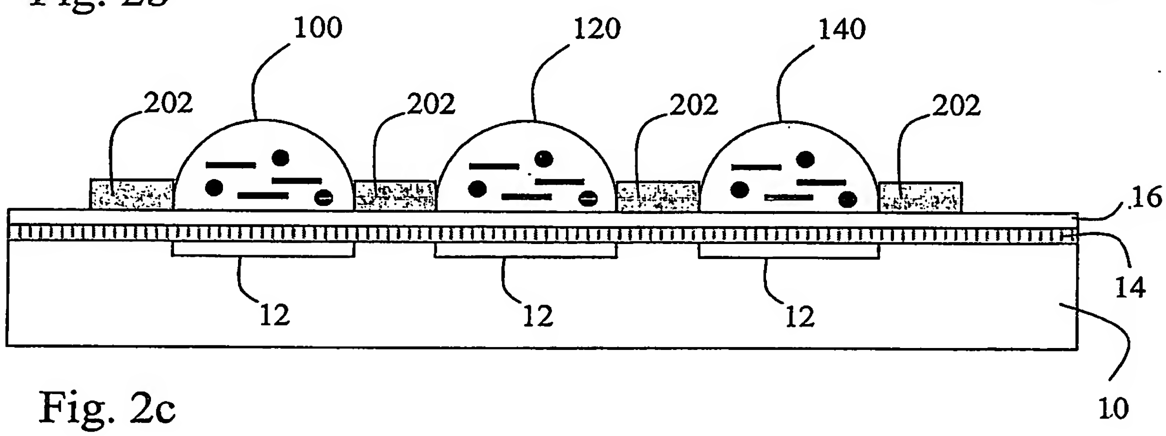


Fig. 2c

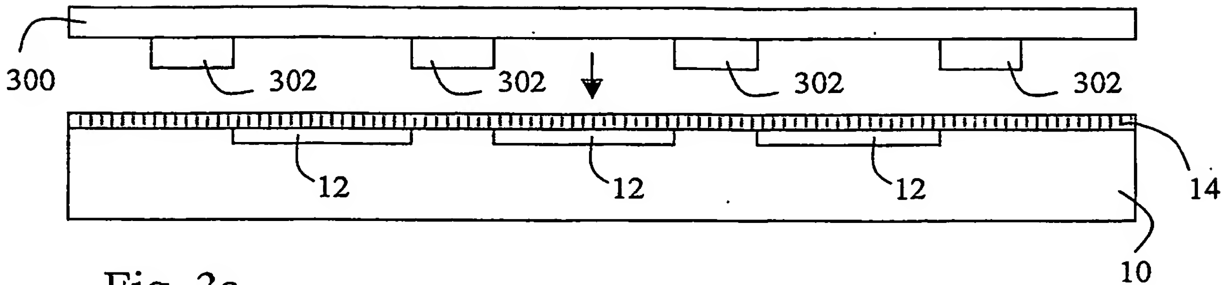


Fig. 3a

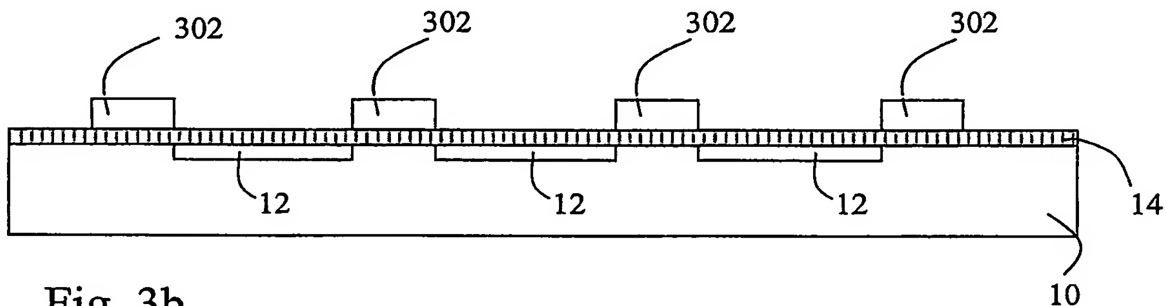


Fig. 3b

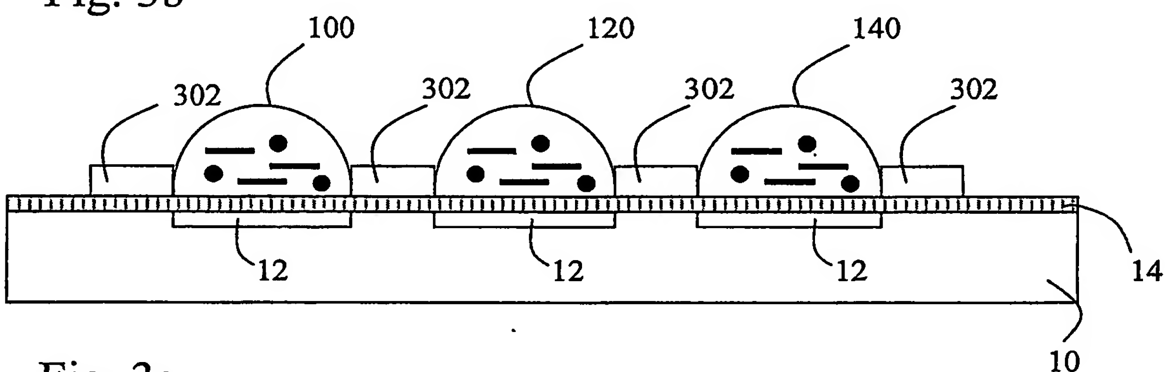


Fig. 3c

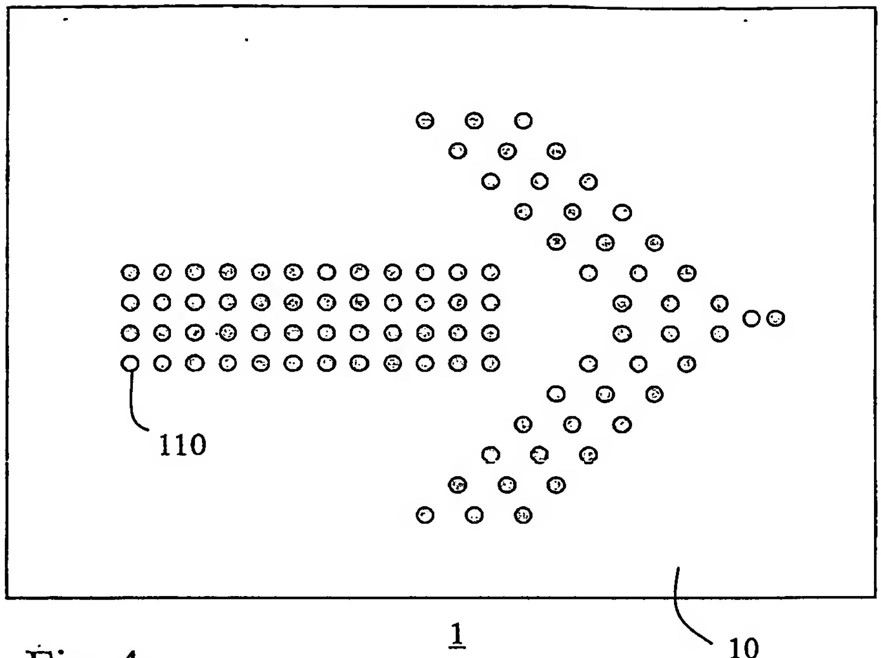


Fig. 4

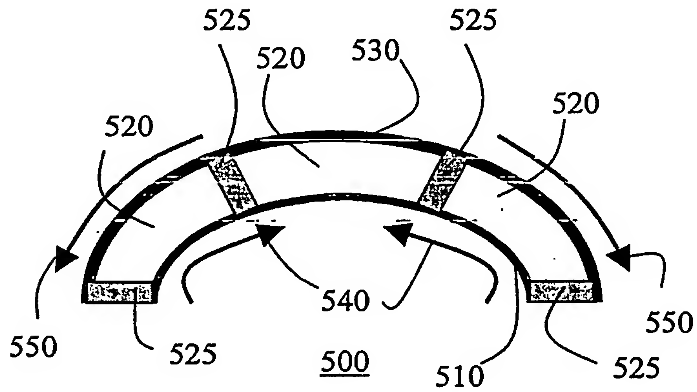


Fig. 5a

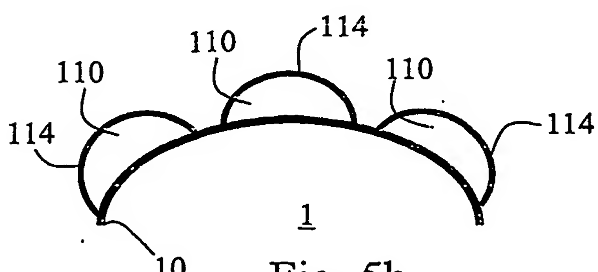


Fig. 5b

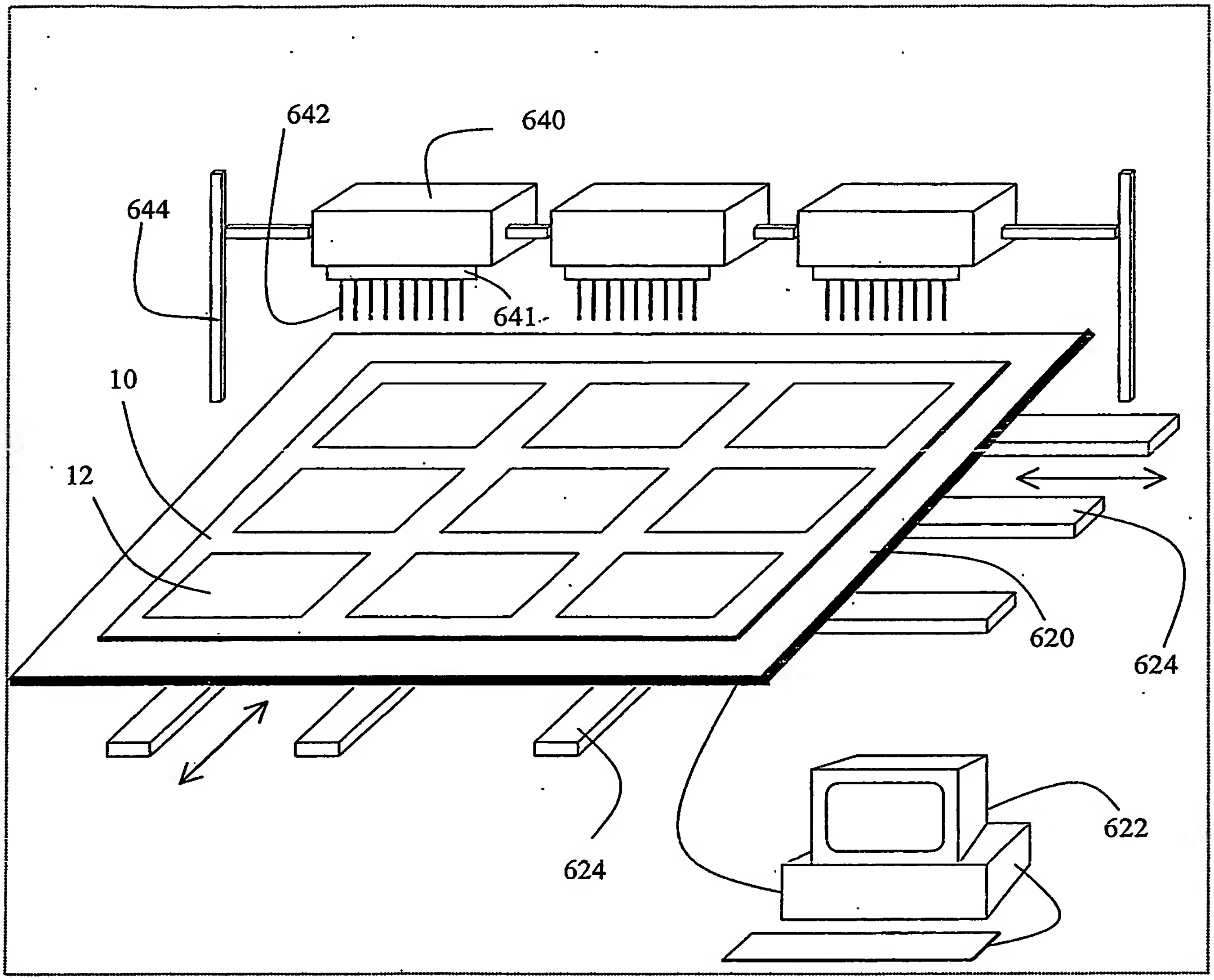


Fig. 6